Tillage impacts on soil property, runoff, and soil loss variations from a Rhodic Paleudult under simulated rainfall

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ABSTRACT: The highly erodible soils of the Tennessee River Valley in northern Alabama have been intensively cropped to cotton (*Gossypium hirsutum* L.), a low-residue crop, and traditionally managed under conventional tillage practices. Conservation tillage systems have potential as management tools for crop production in this region because they tend to reduce soil loss, build up organic matter, and conserve plant available water. Because of changes in tillage (type and timing) and subsequent residue amounts remaining, we evaluated rainfall partitioning and soil loss from a Decatur silt loam (Rhodic Paleudult) cropped to cotton and managed under conventional-till and no-till systems in November 1999 and June 2000. No-till treatments were evaluated with and without fall paratilling and rye (Secale cerale L.) cover. Four tillage-residue treatments evaluated were conventional tillage (fall disk and chisel, spring disk and field cultivated) without paratilling and without cover, no-till without paratilling and without cover, no-till without paratilling and with cover, and no-till with paratill and with cover. Plots (1 m^2) were established on each tillage-residue treatment and exposed to simulated rainfall (50 mm h^{-1} for 2 h). For November 1999, runoff was greatest for non-paratilled no-till plots, whereas for June 2000, conventional-till plots had the greatest runoff. For both dates, no-till /paratill/rye plots had 34% to tenfold less runoff than from other tillage systems, while conventional-till plots had 1.5 to 5.4-fold times more soil loss than from other tillage systems. Paratilling influenced runoff and soil loss more so than surface cover. Paratilling no-till plots reduced runoff by at least 67% in November 1999 (13 months after paratilling) and at least 215% in June 2000 (8 months after paratilling) compared with non-paratilled no-till plots. Sediment from no-till /paratill/rye plots decreased by at least threefold in June 2000 compared with that for November 1999. The worst-case scenario evaluated was the conventional-till treatment. The best-case scenario was the no-till /paratill/rye treatment. No-till /paratill/rye plots averaged 11% and 49% more infiltration than conventional-till plots in November 1999 and June 2000, respectively, whereas conventional-till plots averaged 1.8 and 8.7 times more soil loss than no-till /paratill/rye plots, respectively, for the same two dates. No-till coupled with fall paratilling and a rye cover is the best system to increase infiltration and plant available water and reduce runoff and soil loss for the Tennessee Valley region.

Keywords: Conservation tillage, infiltration, paratill, simulated rainfall

The highly erodible soils of the Tennessee River Valley region in northern Alabama caused some cotton farmers to implement conservation tillage systems in the early 1990s. The predominant tillage system implemented was no-till, in which farmers planted directly into existing cotton (*Gossypium hirsutum* L.) stubble. However, many farmers were reluctant to adopt no-till because of potential yield reductions, changes in soil temperature, and soil compaction (Brown et al., 1985; Burmester et al., 1993), despite potential benefits.

Conservation tillage systems tend to reduce runoff and erosion, enhance infiltration, and increase soil water-holding capacity (Yoo and Touchton, 1988; Blevins et al., 1990; Seta et al., 1993; Edwards et al., 1993; Gaynor and Findlay, 1995; Potter et al., 1995). These systems increase residue and organic matter at the soil surface (Langdale et al., 1992; Reeves, 1997), which increases aggregate stability and soil resistance to raindrop impact and decreases water dispersible clay (Blevins et al., 1990; McGregor et al., 1990; Shaw et al., 2002). However, some studies have shown that differences in runoff from conventional- and conservation-till systems were either negligible (McGregor et al., 1975; Siemens and Oschwald, 1976; Lindstrom et al., 1981; Laflen and Colvin, 1981) or that less runoff (more infiltration) occurs from conventional-till systems than from conservation-till systems (Moldenhauer et al., 1971; Lindstrom and Ontad, 1984; Mueller et al., 1984; Heard et al., 1988; Soileau et al., 1994), especially 1 to 3 years after reduced tillage establishment. These results may be attributed to increased soil density caused by consolidation and/or compaction. NeSmith et al. (1987) and Radcliffe et al. (1988) reported greater bulk density with conservation tillage systems compared with conventional tillage systems. In the Southeast, equipment traffic, implement action, and consolidation compact these weakly-structured surface soils, and deep tillage (or subsoiling) is needed to disrupt compacted zones (Campbell et al., 1974; Reeves and Touchton, 1986; Vepraskas et al., 1987; Reeves and Mullins, 1995). In the Tennessee River Valley, an increase in soil compaction associated with conservation tillage was blamed for poor cotton performance (Burmester et al., 1993), yet Touchton et al. (1986) reported no cotton yield response to spring in-row subsoiling. Spring tillage in Tennessee River Valley soils forms clods that create a rough seed bed that is difficult to plant into. Therefore, soil and hydraulic properties of the near-surface soil altered by tillage change with time, and this rate of change is site-specific.

Paratilling affects rainfall partitioning and erosion by reducing bulk density and cone

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index (Bicki and Guo, 1991; Pierce and Burpee, 1995) and increasing infiltration (Sojka et al., 1993; Rawitz et al., 1994). However, Clark et al. (1993) found that the paratilling impact on infiltration decreased with time, lasting only one year.

Tillage effects on intrinsic soil properties, hydrology, and sediment are time-dependent. Our overall goal was to demonstrate that conservation tillage systems conserve soil and water resources, thus providing farmers in the Tennessee River Valley region with a viable and sustainable alternate management practice for row croplands. Our hypothesis was that differences in infiltration, runoff, and sediment yields throughout the cotton growing season, resulting from long-term tillage-residue management, would be largely due to the different effects these management systems have on soil properties of the near-surface soil with time and/or timing of tillage. Therefore, our objective was to evaluate rainfall partitioning and sediment delivery from a Decatur silt loam cropped to cotton and managed under conventional-till (CT) and no-till (NT) with fall paratilling (+P) and without fall paratilling (-P) and with a rye cover (+C) and without a rye cover (-C).

Methods and Materials

Experimental site. The research site was located in the Tennessee River Valley region of northern Alabama at the Alabama Agricultural Experiment Station in Belle Mina (34.7° N, 86.7° W). The soil studied was a Decatur silt loam, a major soil type in the region, and was classified as a fine, kaolinitic, thermic Rhodic Paleudult (Table 1).

Before simulating rainfall, the research site had been in long-term tillage studies (1990 to present) (Schwab et al., 2002), cropped to cotton and managed under conventional-till and no-till systems. Four tillage-residue treatments, imposed since 1994, evaluated in this study were conventional-till without fall paratilling and without cover (CT-P, NC), no-till without fall paratilling and without cover (NT-P, NC), no-till without fall paratilling and with cover (NT-P, C), and no-till with fall paratilling and cover (NT+P, C). Each tillage-residue treatment was replicated four times. Conventional-till consisted of fall disking and chisel plow, followed by spring disking and cultivator leveling. The paratill® (Bigham Brothers Inc., Lubbock, Texas) was equipped with six shanks on 61 cm spacings, disrupted soil to about 40 cm, and was equipped with a smooth roller. Paratilling and fall disking/chiseling in appropriate treatments was done October 14, 1998, for the November 1999 rainfall simulation and October 18, 1999, for the June 2000 simulation. Each treatment was established on field plots 8 m wide by 15 m long, except for the no-till -P, NC treatment (4 m wide by 15 m long). Data were collected and rainfall simulations were made during November 1999 after cotton harvest and in June 2000, four weeks after the rye cover crop was killed and cotton had been planted.

Soil measurements. Soil samples were taken at selected depths from random locations within each replication of each tillage treatment. When possible, samples were collected in the immediate vicinity of areas designated for simulated rainfall subplots. Soil properties were determined with the following methods: particle size distributions (PSDs) measured by the pipette method (Kilmer and Alexander, 1949), cation exchange capacity (CEC) measured by the NH_4OAc (pH=7) method (Soil Survey Investigations Staff, 1996), soil organic carbon (SOC) measured by the combustion method (Yeomans and Bremmer, 1991), aggregate stability measured by the water stable aggregate method (Kemper and Rosenau, 1986), and bulk density measured by the core method (Blake and Hartge, 1986).

For particle size distributions, samples were air-dried and crushed, and fragments > 2 mm were removed. Particle size distributions were measured by the pipette method, with sands separated into size fractions by sieving.

Soil organic carbon was determined from samples taken from 10 composite samples (20 mm diameter core taken adjacent to rainfall simulation plots). Samples were divided into 0-1, 1-3, 3-6, 6-12, 12-18, and 18-24 cm depth increments. Samples were cleaned of recognizable organic debris, and subsamples were finely ground on a roller mill (Kelly 1994). Subsamples were analyzed for C by automated combustion using a NA 1500 NCS analyzer (Fisons Instruments Inc., Beverly, Massachusetts). Each ground sample was subjected to four determinations for C analysis.

Percentage water stable aggregates (WSA) from the 0-3 cm soil depth (1-2 mm size class) were determined from composite samples taken from five locations adjacent to areas designated for rainfall simulations (Kemper and Rosenau, 1986). Mean water stable aggregates (%) were determined from eight determinations from each composite sample per plot.

Bulk density was determined from 5.4 cm diameter cores taken from three locations and depths (0-15, 15-30, 30-45 cm) adjacent to areas designated for rainfall simulations.

Soil water content was determined gravimetrically (Gardner, 1986) from eight 20 mm diameter cores taken around each rainfall simulation plot. This border area received

Table 1. Selected properties of the Decatur silt loam.

Horizon	Depth	Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)	CEC	pH
	cm		%		$cmol_c/kg$	
			fine, kaolinitic, thermic Rhodic Paleudult			
A_{p1}	0-19	15.3	54.9	30.5	8.91	5.1
A_{p2}	19-30	12.7	51.8	35.5	10.01	5.5
B_{t1}	30-46	10.0	39.4	50.6	11.87	4.6
B_{t2}	46-110	10.0	36.3	53.7	10.49	4.4
B_{t3}	110-150	9.1	27.9	63.0	10.90	4.1

Table 2. Selected soil property data for tillage treatments studied.

Treatment[b]	Properties[a]				
	WSA	SOC_1	SOC_3	SOC_6	Residue Cover
	%	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}
			November 1999		
NT+P, C	48 (05)[c]	1.61 (07)	1.70 (01)	1.12 (02)	2285 (19)
NT-P, C	37 (06)	2.29 (03)	2.18 (03)	0.84 (02)	1865 (09)
NT-P, NC	38 (05)	1.34 (01)	1.33 (01)	0.77 (02)	4640 (02)
CT-P, NC	43 (07)	0.69 (02)	0.75 (03)	0.83 (02)	1415 (29)
			June 2000		
NT+P, C	37 (06)	1.37 (03)	1.25 (01)	1.13 (1)	3996 (17)
NT-P, C	61 (05)	2.58 (03)	1.25 (06)	0.75 (2)	4434 (09)
NT-P, NC	47 (04)	1.71 (01)	1.05 (01)	0.79 (3)	2393 (12)
CT-P, NC	50 (02)	0.94 (03)	0.90 (01)	0.94 (1)	927 (03)

[a] WSA = water stable aggregates (depth = 0-3 cm) (1-2 mm size class); SOC_1, SOC_3, and SOC_6 = mean soil organic carbon values for the 0-1, 1-3 and 3-6 cm soil depths, respectively. Residue cover (dry weights) is from a 1-m^2 area after rainfall simulation.

[b] NT = no-till; CT = conventional-till; P = fall paratill; C = rye cover; NC = no cover.

[c] Values in parentheses are coefficient of variations (cv, %).

the same distribution of simulated rainfall as the test areas. Gravimetric soil water samples were taken just before and after each simulated rainfall event and were separated into 0-1, 1-3, 3-6, 6-9, 9-12, 12-18, and 18-24 cm depth increments.

Rainfall simulations. Duplicate 1 m^2 plots were established on one replicate of each tillage-residue treatment each year (November 8-10, 1999, and June 26-27, 2000). Simulation plots were somewhat randomly placed within each residue-tillage treatment, given the limitation associated with border effects of each residue-tillage treatment. Rainfall simulations were conducted on only one (of four) replicate of each tillage-residue treatment in 1999 and 2000 because of the time-consuming and destructive nature of the simulations. Rainfall simulations conducted in 2000 could not be in the same area where the 1999 rainfall simulations were conducted. Each plot had a slope of ~1%. An area surrounding each 1 m^2 plot was treated like the test area to allow soil material to be splashed in all directions. Simulated rainfall was applied to each 1 m^2 plot at an intensity (I) of 50 mm h^{-1} for 1 h. One hour after the first simulated rainfall event, each 1 m^2 plot received an additional simulated rainfall event (50 mm h^{-1} for 1 h). Rainfall was applied with an oscillating nozzle rainfall simulator (Foster et al., 1982) that used 80100 Veejet nozzles (median drop size = 2.3 mm). The simulator was placed 3 m above each 1 m^2 plot. Well water was used in all simulations (pH = 7.4, EC = 0.17 dS m^{-1}, and total electrolyte concentration = 2 mol$_c$m^{-3}).

Runoff water (R) and sediment yields (E) from each 1 m^2 plot were measured continuously at 5 min intervals during each simulated rainfall event. Runoff and E were collected in 1 L Nalgene (autoclaveable) bottles, with the time required to fill each bottle recorded. Bottles were weighed (bottle+water+sediment), dried at 105 C for 24 h, then weighed again (bottle+sediment). Runoff and E were determined gravimetrically, and infiltration (INF) was calculated by difference (rainfall minus runoff).

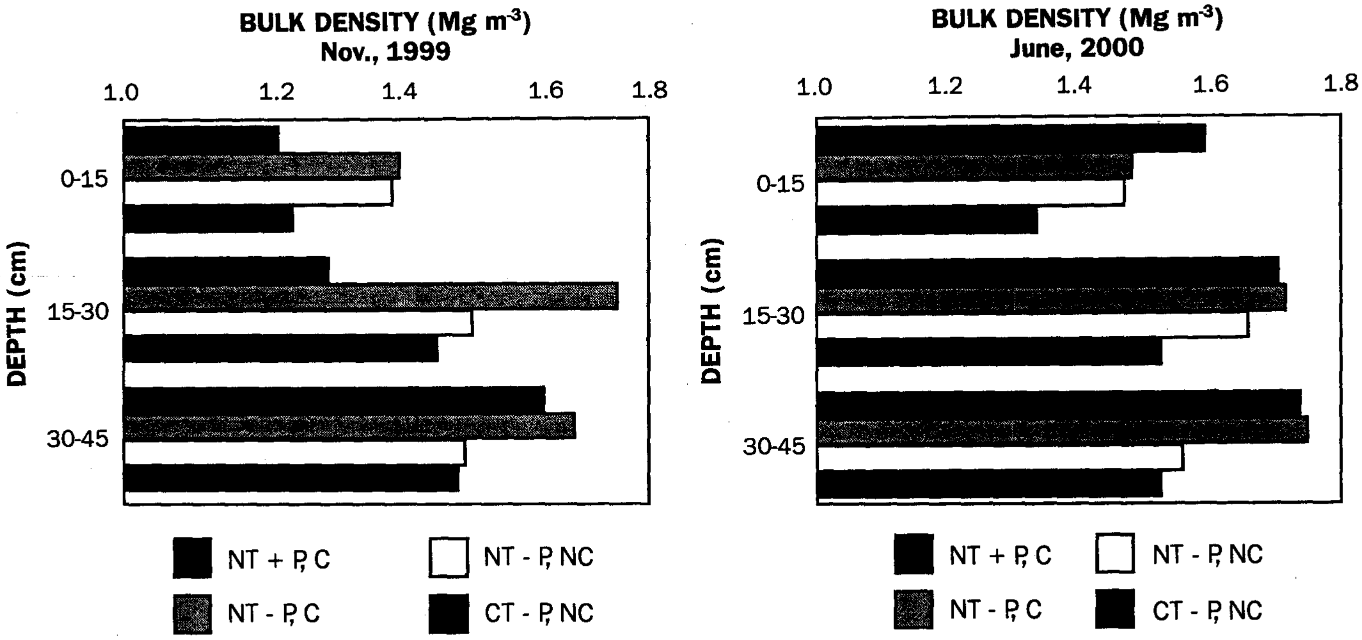
After each simulated rainfall event, all identifiable non-decomposed residue from each 1 m^2 plot was collected, dried at 80°C for 72 h, cleaned of soil particles, and weighed.

Regression analysis was used to determine relationships between dependent and independent variables. Means and coefficient of variations (cv, %) are given for measured data. Because of concerns about rainfall simulation plots not being completely replicated (within replicated tillage treatments), we performed unpaired t-tests (opposed to ANOVA), with the probability level used in evaluating the test statistics set at P = 0.05. Rainfall simulation data may be statistically limited by duplicate subsamples or observations per tillage treatment, yet relative differences in runoff and soil loss were informative and beneficial to producers of the Tennessee Valley. All data analysis was conducted with corresponding functions in Corel WordPerfect Office 2000 Quattro Pro 9.

Results and Discussion

Soil properties. Selected soil properties for each residue-tillage treatment and simulated rainfall event are given in Table 2. Water stable aggregates (WSA) in the 0-3 cm soil layer ranged from 37% to 48% in November 1999 and 37% to 61% in June 2000. For both events (November 1999 and June 2000), significant differences existed among treatment means, with no apparent trends. For example, in November 1999, water stable aggregates values for no-till/paratill/rye plots were at least 12% greater (P = 0.0022) than corresponding values from other treatments, yet water stable aggregate values for conventional-till plots were 13% to 16% greater (P = 0.0003-0.0004) than non-paratilled no-till plots (37%, 38%). In June 2000, water stable aggregate values for no-till/paratill/rye plots were the lowest (37%, P = 0.0008) among treatments evaluated. From November 1999 to June 2000, water stable aggregate values increased (P = 0.0023), except for no-till/paratill/rye plots, by 16% to 65%, with conventional-till plots having the smallest increase with time (16%). Water stable aggregates values for no-till/paratill/rye plots decreased from 48% to 37% (P = 0.0001). Aggregate stability results were mixed and, consequently, do not necessarily correspond well with runoff and sediment losses. Iron (Fe) plays a more significant role in aggregation than soil organic matter in Tennessee Valley soils (Shaw, 2002). These soils contain appreciable Fe quantities—between 2.6% and 2.9% in the 0-1 cm soil depth. Furthermore,

Figure 1
Bulk density (Mg m-3) by depth for conventional- (CT) and no-till (NT) plots (November 1999, June 2000).

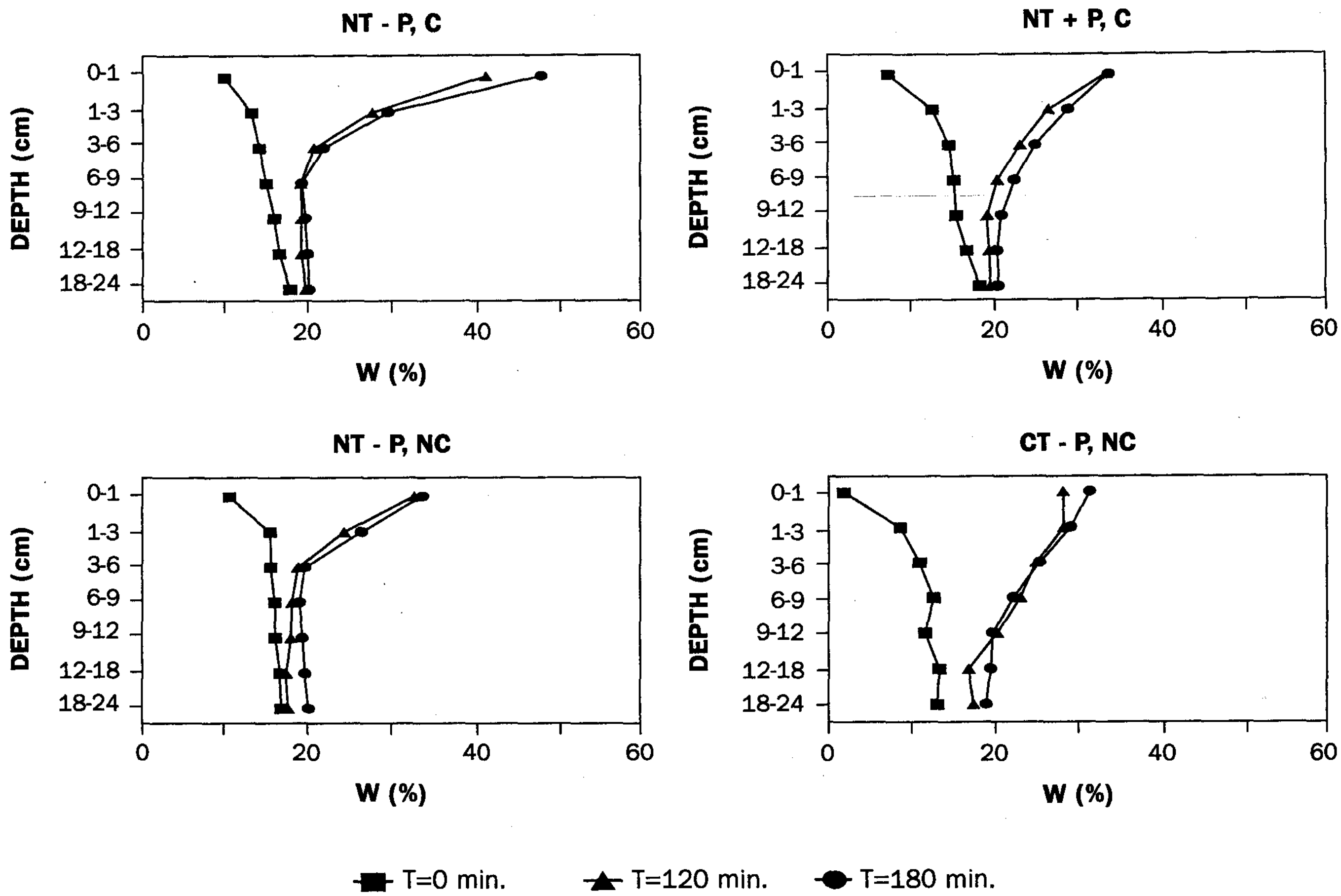


the 1-2 mm size class utilized in the water stable aggregate procedure may not represent aggregate stability characteristics of the whole soil. Aggregate breakdown characteristics are different for aggregate size classes than for whole soil, especially for highly weathered soils of the Southeast (Truman et al. 1990). Also, the water stable aggregate procedure evaluates stability of 1-2 mm aggregates due to forces (slaking) associated with flowing water. Disruptive (slaking) forces, created by buildup of entrapped air inside aggregates, tend to be greater than binding forces holding aggregates together and dominate stabilities in the water stable aggregate procedure. For our experimental setup, evaluating aggregate stability of the whole soil due to forces associated with raindrop impact would be more representative if relating aggregate stability to changes in infiltration, runoff, and soil detachment. Finally, factors or processes affecting sediment transportability are more important than those affecting the binding of soil particles into aggregates (detachability). When transport-limiting conditions exist, measures of aggregate stability may not correlate well with runoff and sediment delivery.

Bulk density (BD) values (0-15 cm) from conventional-till plots in November 1999 (1.22 Mg m^{-3}, cv = 9%) were numerically (not significantly) lower than corresponding values from other tillage treatments (Figure 1). In November 1999, bulk density values for the four tillage treatments were similar. In June 2000, bulk density values in the top 15 cm of conventional-till plots were numerically greater (1.54 Mg m^{-3}, cv = 4%) than corresponding values from other tillage treatments. In June 2000, the only significant difference (P = 0.03) found between bulk density values was those from paratilled no-till plots (NT+P, C, 1.31 Mg m^{-3}, cv = 9%) and conventional-till plots (CT-P, NC, 1.54 Mg m^{-3}, cv = 4%). The November 1999 simulation was right after tillage in conventional-till plots, thus the relatively low bulk density values, whereas the June 2000 simulation was 4 to 6 weeks after tillage, and reconsolidation had occurred in conventional-till plots. Paratilling numerically reduced bulk density values (0-15 cm) in no-till plots by about 11% (November 1999) and 9% (June 2000) compared with non-paratilled no-till plots. Even though these differences are not significant, reduction in bulk density by paratilling equates to 5.5% (November 1999) and 4.7% (June 2000) more porosity in no-till/paratill/rye plots compared with non-paratilled no-till plots, which could impact infiltration and runoff amounts. Paratilling effects were not evident in the 15-30 or 30-45 cm depths for both dates. From November 1999 to June 2000, bulk density values for all tillage treatments and depths numerically increased up to 26%, with conventional-till plots having the greatest increases (26% for 0-15cm, P = 0.02; 27% for 15-30 cm, P = 0.001; and 5% for 30-45 cm, not significant).

Mean soil organic carbon (SOC) values (Table 2) are given for the 0-1, 1-3, and 3-6 cm soil depths. Over the top 6 cm of soil for both dates, no-till plots averaged 92% more soil organic carbon than conventional-till plots (1.46 vs. 0.76 g kg^{-1}) in November 1999 (P = 0.0001) and 42% more soil organic carbon (1.32 vs. 0.93 g kg^{-1}) in June 2000 (P = 0.0001). For both dates and within no-till plots, soil organic carbon values generally decreased with depth for all plots, with little difference occurring below 6 cm. Even though soil organic carbon values numerically decreased within no-till plots, soil organic carbon values for 0-1 and 1-3 cm depths were statistically similar. Although not significant for all depths, no-till plots with rye cover generally had greater soil organic carbon values than plots without rye cover. Soil organic carbon values for the 0-1 cm soil layer averaged 1.82 g kg^{-1} for no-till plots, whereas soil organic carbon values for conventional-till plots averaged 0.82 g kg^{-1} (a difference of 123%) (P = 0.01). Differences in soil organic carbon values for the 0-1 cm layer can influence rainfall partitioning, soil detachment, sediment transport, and agrichemical fate and transport (Truman et al., 1998). As for residue cover, no-till plots had numerically more residue cover than conventional-till

Figure 2
Gravimetric water content (w, %) by depth for conventional- (CT) and no-till (NT) plots (June 2000). Water contents are given for the beginning of the first simulated rainfall event (t=0 min), at the beginning of the second simulated rainfall event (t=120 min), and at the end of all simulated rainfall (t=180 min).



plots for both dates (Table 2). In June 2000, no-till plots with cover had about two times more residue cover than no-till plots without cover (P = 0.03) and about four times more residue cover than conventional-till plots (P = 0.05). The trend did not hold for November 1999. Residue cover in November 1999 (after harvest) was mostly composed of cotton biomass alone rather than rye cover, whereas residue cover in June 2000 was mostly from the rye cover. Residue cover amounts influence infiltration, runoff, and erosion occurring under reduced tillage conditions (Lindstrom et al., 1984; Freebairn and Gupta, 1990; Bradford and Huang, 1994). Also, no-till +P plots had the highest seed cotton yields, 16% greater than conventional-till and 10% greater than no-till -P (Schwab et al., 2002).

Gravimetric water contents (w, %) with depth for conventional-till and no-till plots are given in Figure 2 (June 2000). Water contents are given at the beginning of the first simulated rainfall event (t = 0 min), at the beginning of the second simulated rainfall event (t = 120 min), and at the end of the second simulated rainfall event (t = 180 min). At t = 0 min, the greatest difference in water contents occurred at the 0-1 cm depth with no-till plots (~9%) having a 6.5-fold increase in gravimetric water compared with conventional-till plots (~1.5%). Differences in water content between tillage treatments occurred in the 1-3 cm depth (~2 fold increase), but relatively little change occurred for conventional-till and no-till plots below 6 cm. Water content differences throughout the soil profile of each tillage treatment can be further illustrated by differences in porosity (f, calculated from bulk density values) and equivalent depth of water (EDW, cm) in the top 24 cm (only bulk density data shown). No-till plots averaged 13% more f in the soil surface and had 48% greater Δf ($\Delta f = f_{max}$-f_{min}) value than conventional-till plots. Also, after applying 50 and 100 mm of rainfall, equivalent depth of water values were similar among tillage treatments. However, equivalent depth of water values at t = 0 (before simulating rainfall) for no-till plots (5.6 cm) were 31% greater than conventional-till plots (4.3 cm) indicating that no-till plots retained more water in the soil profile than conventional-till from previous (natural) rainfalls. Differences in water contents among tillage systems have been reported and modeled (Moroizumi and Horino, 2002) and, subsequently, affect runoff and soil loss amounts (Luk, 1985; Truman and Bradford, 1993).

Runoff and sediment delivery, November 1999. Runoff, infiltration, and sediment yields for treatments and simulated rainfall events studied are presented in Table 3 and Figure 3. Runoff rates increased during the

Table 3. Runoff (R), infiltration (INF), and sediment (E) losses for the first (0-60 min) and second (60-120 min) simulated rainfall events.

Treatment[a]	R[b] mm/h	R_{max} mm/h	INF mm/h	INF_{min} mm/h	R %	INF %	E g
			Nov., 1999				
			(0-60 min)				
NT+P, C	7.8 (56)[c]	13.4 (62	46.8 (09)	41.2 (20)	14.3	85.7	60.9 (35)
NT-P, C	20.4 (60)	33.2 (45)	30.6 (41)	17.8 (84)	40.1	59.8	77.6 (62)
NT-P, NC	13.1 (23)	24.7 (15)	40.4 (07)	28.8 (13)	24.5	75.5	29.2 (16)
CT-P, NC	10.5 (32)	16.7 (14)	41.3 (08)	35.1 (06)	20.3	79.7	112.4 (15)
			(60-120 min)				
NT+P, C	17.6 (48)	20.2 (41)	38.3 (22)	35.7 (23)	31.5	68.5	91.7 (35)
NT-P, C	30.5 (37)	40.2 (24)	21.4 (52)	11.7 (81)	58.8	41.2	64.3 (52)
NT-P, NC	33.9 (05)	42.7 (02)	18.3 (08)	9.7 (08)	64.9	34.9	35.1 (06)
CT-P, NC	24.8 (14)	31.1 (11)	26.4 (13)	20.8 (17)	48.4	51.5	150.3 (33)
			June, 2000				
Treatment	**R mm/h**	**R_{max} mm/h**	**INF mm/h**	**INF_{min} mm/h**	**R %**	**INF %**	**E g**
			(0-60 min)				
NT+P, C	2.6 (28)	2.9 (28)	47.5 (03)	47.2 (03)	5.2	94.8	24.3 (18)
NT-P, C	9.4 (13)	30.8 (01)	41.9 (12)	20.6 (18)	18.6	81.4	38.7 (48)
NT-P, NC	8.2 (29)	17.5 (29)	40.6 (06)	31.3 (17)	16.8	83.2	45.4 (24)
CT-P, NC	18.1 (02)	36.1 (03)	31.7 (06)	13.8 (05)	36.5	63.5	136.9 (29)
			(60-120 min)				
NT+P, C	3.6 (25)	4.4 (13)	47.2 (03)	46.5 (02)	7.1	92.8	21.9 (11)
NT-P, C	34.0 (01)	45.1 (03)	18.0 (21)	6.9 (33)	65.7	34.3	58.5 (35)
NT-P, NC	26.9 (11)	34.0 (13)	22.9 (12)	15.9 (27)	54.1	45.9	65.3 (07)
CT-P, NC	38.2 (00)	42.7 (00)	13.4 (00)	8.9 (00)	74.1	25.9	261.3 (00)

[a]NT = no surface tillage; CT = conventional-till; P = fall paratill; C = Cover (Rye); NC = No Cover (no Rye).

[b]R (mm/h), INF (mm/h), and E (g) are runoff, infiltration, and sediment losses for the 0-60 and 60-120 min time periods, respectively.
R (%) and INF (%) are percentages of rainfall that were runoff and infiltration for the 0-60 and 60-120 min time periods, respectively.
R_{max} and INF_{min} (mm/h) are maximum runoff and minimum infiltration rates for their respective simulated rainfall events.

[c]Values in parentheses are coefficients of variations (%). Target rainfall intensities were 50 mm h^{-1}.

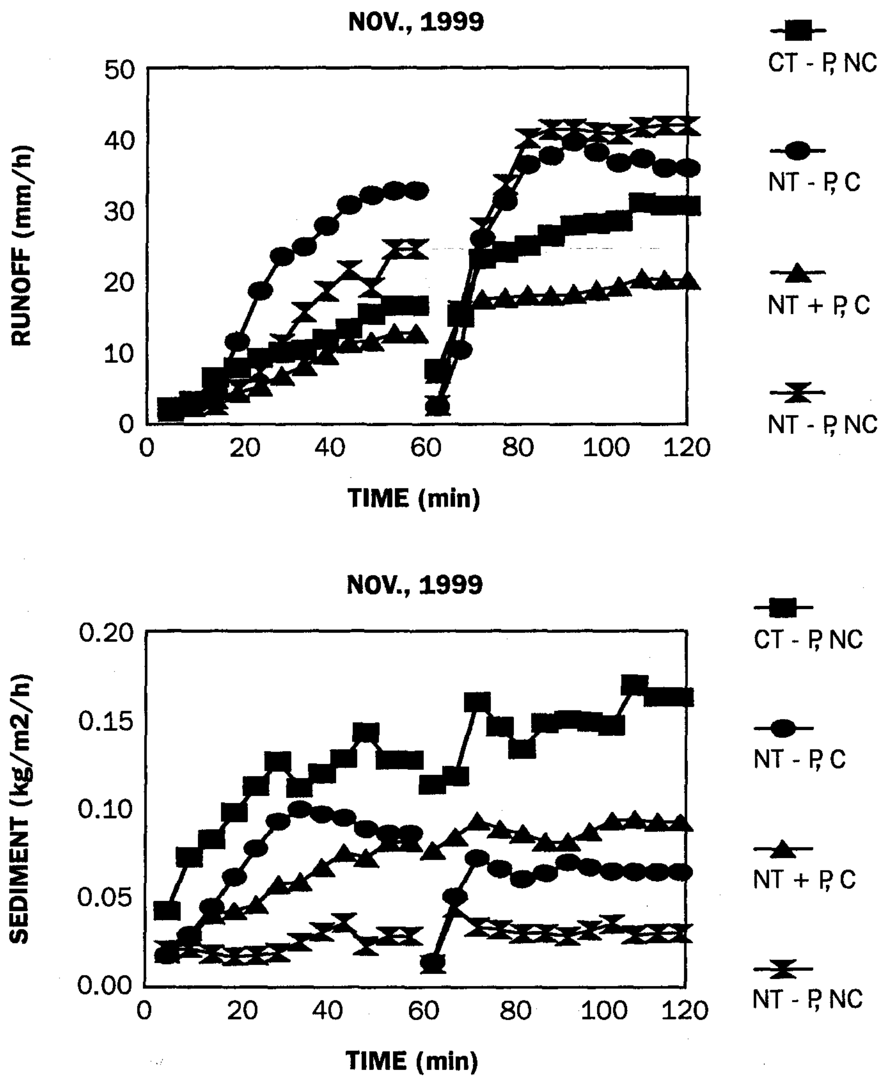
first simulated rainfall event (0-60 min), then reached steady-state rates during the second (60-120 min) simulated rainfall event (Figure 3). Runoff (Table 3) was numerically greatest for no-till -P plots (R_{60}=16.8 mm h^{-1} and R_{120} = 32.2 mm h^{-1}), and lowest for no-till/paratill/rye plots (R_{60}=7.8 mm h^{-1} and R_{120} = 17.6 mm h^{-1}). No-till/paratill/rye plots had about 2 times less runoff (R_{60} and R_{120}) than paratilled no-till plots and 34% and 40% less runoff than conventional-till plots. Similar trends were found for maximum runoff rates (R_{max}). Paratilling numerically reduced bulk density values (0-15 cm) in no-till plots by about 11%, while disking and chisel plowing conventional-till plots numerically reduced bulk density values by about 10%. No-till/paratill/rye plots had the lowest runoff amounts and rates among tillage treatments. Also, runoff rates from non-paratilled no-till plots increased faster than that from no-till/paratill/rye plots. By reducing bulk density, paratilling increased infiltration, decreased runoff amounts and rates, and maintained residue on the soil surface. Others have reported similar results (Bicki and Guo, 1991; Sojka et al., 1993; Rawitz et al., 1994; Pierce and Burpee, 1995).

Sediment rates increased during the first simulated rainfall event (0-60 min), then reached steady-state rates (Figure 3). Conventional-till plots had the greatest steady-state sediment yields (~0.15 kg m^{-2} h^{-1}), while all no-till plots had steady-state rates below 0.1 kg m^{-2} h^{-1}. E_{60} and E_{120} values were greatest for conventional-till plots (E_{60} = 112.4 g and E_{120} = 150.3 g) (P = 0.04), with conventional-till plots having at least 1.5 times more soil loss than no-till plots for the first (0-60 min, E_{60}) and second (60-120 min, E_{120}) simulated rainfall event (Table 3). In the past, many farmers in this region commonly used conventional tillage, a "worst-case" scenario in terms of soil loss among treatments studied. This trend is currently rapidly changing because of the benefits of reduced-tillage systems.

June 2000. Rainfall simulations occurred 4 weeks after killing the rye and planting cotton. However, measurements are still relevant in that they represent conditions until maximum cotton canopy development in late July, even when canopy often does not completely close. Runoff rates for conventional-till and non-paratilled no-till plots increased during the first 60 min of simulated rainfall, then reached steady-state rates during the second (60-120 min) simulated rainfall event (Figure 5). Runoff rates for the no-till/paratill/rye treatment remained relatively constant—never exceeding 5 mm h^{-1}. No-till plots averaged 2.7 times (170%) less runoff (P = 0.002) than conventional-till plots for the first (R_{60}) simulated rainfall event and 1.8 times (77%) more runoff (P = 0.1) than conventional-till plots for the second (R_{120}). Runoff amounts were numerically greatest for conventional-till plots (R_{60} = 18.1 mm h^{-1}, P = 0.02 and R_{120} = 38.2 mm h^{-1}, NS) and lowest for no-till/paratill/rye plots (R_{60} = 2.6 mm h^{-1}, P = 0.1 and R_{120} = 3.6 mm h^{-1}, P = 0.01). No-till/paratill/rye plots had 3 (P = 0.04) and 8 (P = 0.0009) times less runoff (R_{60} and R_{120}) than non-paratilled no-till plots and 7 (P = 0.002) and 10 (P = 0.002) times less runoff (R_{60} and R_{120}) than conventional-till plots. Similar trends were found for maximum runoff rates (R_{max}). Bulk density values

Figure 3

Runoff, mm h^{-1}, and sediment yields, kg m^{-2} h^{-1}, from conventional- (CT) and no-till plots (NT) during the 2 h of simulated rainfall (I=50 mm h^{-1}) (November 1999).



in June 2000 for conventional-till plots (0-15 cm) were numerically (9%) greater than that for no-till plots. Also, fall paratilling numerically decreased bulk density values (0-15 cm) in no-till plots by about 9%. No-till /paratill/rye plots had the lowest runoff amounts (R_{60}, R_{120}) and rates (R_{max}). Also, runoff rates from non-paratilled no-till plots increased faster than that from no-till /paratill/rye plots. Like in the November 1999 simulation, fall paratilling and residue cover reduced bulk density, increased infiltration, and decreased runoff.

Sediment rates increased during the first simulated rainfall event, then reached steady-state values (Figure 4). Conventional-till plots had the greatest steady-state sediment yields (~0.3 kg m^{-2} h^{-1}), while all no-till plots had steady-state rates below 0.1 kg m^{-2} h^{-1}. No-till plots averaged ~4 times less sediment yield (P = 0.1) than conventional-till plots for the first simulated rainfall event (E_{60}) and 5.4 times less sediment yield (P = 0.1) than conventional-till plots for the second (E_{120}) (Table 3). E_{60} and E_{120} values were numerically greater for conventional-till plots (E_{60} = 136.9 g and E_{120} = 261.3 g) and least for no-till/paratill/rye plots (E_{60} = 24.3 g and E_{120} = 21.9 g). The no-till/paratill/rye treatment was effective in limiting sediment delivery compared with non-paratilled no-till and conventional-till systems.

November 1999 vs. June 2000. Changes in soil properties and tillage (timing and type) during the cotton season influenced seasonal runoff and soil losses from each treatment. We were particularly interested in comparing rainfall partitioning and soil loss differences as a function of no-till and conventional-till systems, paratilling, and time of growing season. For conventional-till plots, runoff and soil loss numerically increased by at least 1.5 times (>50%) in June 2000 compared with that in November 1999 (Table 3). Conventional-till plots were chisel plowed in the fall, followed by spring disking and cultivator leveling. Greater runoff and soil loss in June 2000 were most likely caused by reconsolidation and surface seal development on conventional-till plots after disking, leveling, seedbed preparation, and planting.

Mixed results were obtained for non-paratilled no-till plots. Numerically, non-paratilled no-till plots had decreased runoff (17-34%) in June 2000 compared with that in November 1999, probably because of differences in crop residue. For sediment, non-paratilled no-till plots without rye cover had increased sediment yields (72%) in June 2000 compared with that in November 1999, a result of more cotton residue in the fall (Table 2). Conversely, non-paratilled no-till plots with rye cover had decreased sediment yields (46%) in June 2000 compared with that in November 1999 because of surface residue differences (4,438 vs. 1,865 kg ha^{-1}, Table 2). Based on this data, a cover rye practice is beneficial in terms of reducing sediment losses in no-till systems.

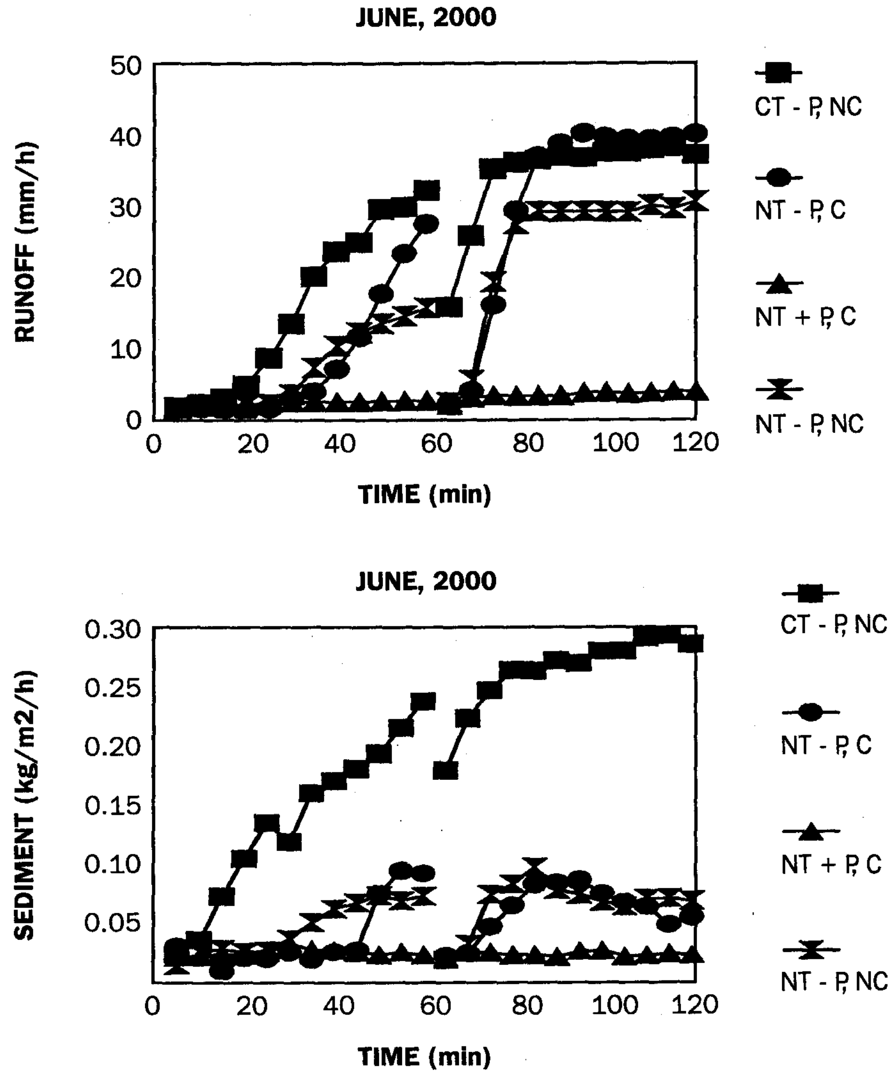
The greatest differences in runoff and sediment delivery between November 1999 and June 2000 rainfall simulations occurred in no-till/paratill/rye plots. Runoff (by at least fourfold, or 300%) and soil loss (by at least threefold or 200%) decreased in June 2000 compared with corresponding values for November 1999. Paratilling occurred for the November 1999 and June 2000 rainfall simulations 13 and 8 months, respectively, before the corresponding simulation. From our limited (two data points) data, paratilling effects tended to decrease with time since paratilling. Paratilling no-till plots reduced runoff by at least 67% in November 1999 (13 months since paratilling) and by at least 215% in June 2000 (8 months since paratilling) compared with non-paratilled plots. Clark et al. (1993) found that paratilling impact on infiltration (and runoff) decreased with time, lasting only 12 months. Paratilling eliminates compaction/consolidation, which is common under reduced tillage conditions (Bicki and Guo, 1991; Pierce and Burpee, 1995). In soils where the soil surface does not limit infiltration, near-surface subsurface layers can limit vertical water movement. Paratilling breaks up these dense soil layers, thus maintaining percolation and infiltration, and subsequently reduces runoff (Tables 2 and 3, Figures 1-4).

From our data, no-till/paratill/rye plots represented the best-case scenario, and conventional-till plots represented the worst-case scenario. We assumed that differences in runoff and sediment losses between respective tillage types at the beginning and end of the growing season were due to cover, changes in intrinsic soil properties, and/or paratilling. The relatively large impact of paratilling has been discussed. Differences in rye cover and intrinsic soil properties were evident among tillage treatments for a given rainfall simulation (Table 2). Surface cover and soil organic carbon are directly related to how a soil surface responds to raindrop impact and surface seal development, as well as subsequent infiltration, runoff, soil detachment, and sediment transport. However, in this study, neither property provided a clear explanation for differences in runoff and soil loss among tillage treatments for a given simulation and between the two simulations.

Farmers want to know how a particular tillage system will affect how much rainfall infiltrates into the soil during the growing season, thus becoming available for plant uptake. Over the 2 h simulated rainfall duration in June 2000 (4 weeks after planting), 16% more of the total rainfall ran off conventional-till plots (55%) than for non-paratilled no-till plots (39%) (Table 3). This translates into 16% more of the total rainfall infiltrated non-paratilled no-till plots (61%) compared with conventional-till plots (45%). Similarly, 33% more of the total rainfall ran off non-paratilled no-till plots (39%) than for no-till/paratill/rye plots (6%). This translates into 33% more of the total rainfall infiltrated no-till/paratill/rye plots (94%) compared with non-paratilled no-till plots (61%). Given the rainfall intensity (50 mm h^{-1}) and assuming that evapotranspiration was 6 mm d^{-1}, then 45 mm of water infiltrated into conventional-till plots, 61 mm infiltrated into non-paratilled no-till plots, and 94 mm infiltrated no-till/paratill/rye plots, resulting in 7.5 days of water for crop use in conventional-till plots, 10.2 days of water in non-

Figure 4

Runoff, mm h^{-1}, and sediment yields, kg m^{-2} h^{-1}, from conventional- (CT) and no-till plots (NT) during the 2 h of simulated rainfall (I=50 mm h^{-1}) (June 2000).



paratilled no-till plots, and 15.7 days of water in no-till/paratill/rye plots. Therefore, no-till/paratill/rye plots have about 2.1 times (109%) more days of water than conventional-till plots and 1.5 times (54%) more days of water than non-paratilled no-till plots. For sediment, conventional-till plots averaged 3.5, 4.0, and 8.7 times more soil loss than non-paratilled no-till plots, non-paratilled no-till plots with rye cover, and no-till/paratill/rye plots, respectively. Likewise, for November 1999, no-till/paratill/rye plots had at least 16% more days of water than non-paratilled no-till and conventional-till plots. CT plots averaged 4.1, 1.9, and 1.8 times more soil loss than non-paratillled no-till plots without rye cover, non-paratilled no-till plots with rye cover, and no-till/paratill/rye plots, respectively. Removing cover in no-till plots had less impact on sediment reduction than paratilling. The no-till/paratill/rye treatment was the most effective in limiting runoff, maximizing infiltration and plant available water, and minimizing sediment losses. This is extremely important at the beginning of the cotton-growing season when trying to establish acceptable plant stands.

Summary and Conclusion

In November 1999 and June 2000, we evaluated rainfall partitioning and sediment delivery from a Decatur silt loam cropped to cotton and managed under conventional- and no-till treatments. Four tillage-residue treatments evaluated were conventional tillage without fall paratilling and without rye cover (CT-P, NC), no-till without fall paratilling and without cover (NT-P, NC), no-till without fall paratilling and with cover (NT-P, C), and no-till with fall paratilling and cover (NT+P, C). Each 1 m^2 plot was exposed to 2 h of simulated rainfall ($I = 50$ mm h^{-1}), and runoff and soil loss were measured continuously. The following conclusions can be made:

(1) No-till treatments promoted soil organic carbon buildup. Over the top 6 cm of soil, no-till plots averaged 92 and 42% more soil organic carbon than conventional-till plots in November 1999 (1.46 vs. 0.76 g kg^{-1}) and June 2000 (1.32 vs. 0.93 g kg^{-1}), respectively. Soil organic carbon values (0-1 cm) averaged 1.82 g kg^{-1} for no-till plots, whereas soil organic carbon values for conventional-till plots averaged 0.82 g kg^{-1} (123% difference).

(2) For November 1999, runoff was greatest for non-paratilled no-till plots. For June 2000, conventional-till plots had the greatest runoff. For both dates, no-till/paratill/rye plots had 34% to tenfold less runoff than from other tillage systems. Also, conventional-till plots had 1.5- to 5.4-fold times more soil loss than from other tillage systems.

(3) Comparing November 1999 to June 2000 results, conventional-till plots had at least 50% more runoff and soil loss in June 2000. All non-paratilled no-till plots had decreased runoff (17-34%) in June 2000. However, in June 2000, non-paratilled no-till plots without cover had increased sediment yields (72%), whereas non-paratilled no-till plots with cover had decreased sediment yields (46%) compared with that in November 1999. Rye cover was effective in reducing soil loss in no-till systems. For no-till/paratill/rye plots, runoff and soil loss decreased by at least four and threefold respectively in June 2000 compared with corresponding values for November 1999.

(4) Paratilling influenced runoff and soil loss more so than surface cover. Paratilling no-till plots reduced bulk density values (0-15 cm) by ~10% (increased porosity by ~5%), resulting in no-till/paratill/rye plots having reduced runoff by at least 67% in November 1999 (13 months after paratilling) and at least 215% in June 2000 (8 months after paratilling) compared with non-paratilled no-till plots. In June 2000, no-till/paratill/rye plots had the least soil loss. From our limited dataset, paratilling reduced runoff and sediment delivery from no-till systems and its effect tends to decrease with time since paratilling.

(5) The worst-case scenario evaluated in terms of infiltration, runoff, and soil loss was the conventional-till treatment. The best-case scenario was the no-till/paratill/rye treatment. No-till/paratill/rye plots averaged 37% less runoff and 12% more infiltration than conventional-till plots in November 1999, while in June 2000, no-till/paratill/rye plots averaged 8 times less runoff and 2.5 times more infiltration than conventional-till plots. No-till/paratill/rye plots had at least 16% (November 1999) and 100% (June 2000) more days of water for crop use than conventional-till plots. Conventional-till plots averaged 1.8 times (November 1999) and 8.7 times (June 2000) more soil loss than no-till/paratill/rye plots. No-till coupled with fall paratilling and a rye cover crop is the best system to increase cotton yields (Schwab et al., 2002), reduce runoff, increase infiltration and plant available water, and reduced sediment loads for the Tennessee Valley region.

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